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Final Summary of Research Report

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Principal Investigator: Dr. Jeffry Kruk

Overview:

The goal of this project was to gain new insight into both the true temperatures of the central stars of planetary nebulae and their evolutionary histories. The temperature scale of the hottest central stars of planetary nebulae is poorly known. The temperature diagnostics available at visible wavelengths are not useful for these very hot stars, or suffer from as-yet unresolved systematic uncertainties. However, the combination of FUSE FUV spectra and HST NUV spectra allows precise temperature determinations by utilizing ionization balances of C III, C IV and O V, O VI lines.

The sample comprises hot hydrogen-rich central stars covering the hottest phase of post-AGB evolution ($T_{\text{eff}} > 70,000\text{K}$). The spectra were analyzed with fully metal line blanketed NLTE model atmospheres in order to determine T_{eff} , surface gravity, and chemical composition. In addition to the temperature scale, the spectra help address the question of metal abundances at the surface of these stars. Depending on the particular star, the metal abundances are either dominated by ongoing diffusion processes or they originate from dredge-up phases during previous AGB evolution. The sample was selected so as to include objects that were expected to exhibit both processes, in order to assess their relative importance and to gain insight into the evolutionary history of the stars. The objects that show qualitatively a metal abundance pattern which points at dredge-up phases, can be used to quantitatively check against abundance predictions of stellar evolution theory. The other objects, where gravitational diffusion and radiative acceleration determine the photospheric metal

abundances, will be used to check our NLTE models which for the first time include diffusion processes self-consistently.

Results:

All of the proposed program stars were observed, and spectra of a few other stars that were observed under other programs were included in the sample. An unexpected aspect of the spectra was the presence of Fe VI and Fe VII lines, which provide an additional sensitive temperature diagnostic that complements the planned light-element measurements. Temperatures were determined with an estimated accuracy of 5%, and surface gravities were determined to within 0.2 dex. In all cases the new temperatures were higher than those of previous determinations, by amounts ranging from 10% to over 50%.

Interesting preliminary results from the metal abundance studies are available, but considerable additional analysis is required. The H-rich CSPN observed in this program show considerable differences as a group when compared to the H-deficient CSPN (observed under other programs). These differences provide considerable support for the hypothesis that the latter group were formed by the late helium shell flash that returns

the star to the AGB for additional nuclear burning (the so-called "born again AGB star" scenario). Within the group of H-rich CSPN, abundances are typically within a factor of two of solar, but with variations in a few instances ranging from 1/20th solar to 20 times solar. Detailed modelling of diffusion processes is still ongoing, but initial results are generally consistent with the observed abundance patterns for the stars with near-solar abundances. The star with abundances that differ most from solar appears to be a metal-poor halo star.

The main result of the abundance studies is one that was not anticipated: the discovery of fluorine in nearly all of the H-rich CSPN. The abundances were roughly solar, indicating that little or no processing of fluorine occurred in the envelope of the star. This is generally consistent with current models of the evolution of the H-rich CSPN from low-mass stars.

The following publications have resulted from this grant:

Werner, K., Rauch, T., Kruk, J.W. 2005, "Fluorine in extremely hot post-AGB stars: evidence for nucleosynthesis", A&A 433 641

Werner, K., Rauch, T., Kruk, J.W., 2005, "Insight into AGB and post-AGB stellar evolution with FUSE", Astrophysics in the Far Ultraviolet, ASP Conference Series, Sonneborn, Moos, & Andersson eds.

Werner, K., Deetjen, J.L., Dreizler, S., Rauch, T., Kruk, J.W., 2003, "Temperature scale and iron abundances of very hot central stars of planetary nebulae", IAU Symposium No. 209, ASP Conference Series Dopita, ed.

Traulsen, I., Hoffmann, A.I.D., Rauch, T., Werner, K., Dreizler, S., Kruk, J.W., 2005, "HST and FUSE spectroscopy of hot hydrogen-rich central stars of planetary nebulae", 14th European Workshop on White Dwarfs, Koester & Mohler, eds.

Hoffmann, A.I.D., Traulsen, I., Rauch, T., Werner, K., Dreizler, S., Kruk, J.W., 2005, "Iron abundance in hydrogen-rich central stars of planetary nebulae", 14th European Workshop on White Dwarfs, Koester & Mohler, eds.

Koesterke, L., Werner, K., Kruk, J.W., Lanz, T., 2004, "NGC 1535: UV observations and models", Asymmetric Planetary Nebulae III, ASP Conference Series, Meixner, Kastner, Balic, & Soker eds.


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